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SPACE ENVIRONMENT STUDIES FROM CRRES, APEX, AND DMSP SATELLITE DATA

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"This technical report has been reviewed and is approved for publication"

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The Institute for Scientific Research (ISR) of Boston College was contracted by the Space Physics Division (GPS) of the Phillips Laboratory (PL) Geophysics Directorate to perform research in the area of Space Particle Modeling and Effects. A number of computer models and simulations were developed by use of the data from various spacecraft including the Combined Release and Radiation Effects Satellite (CRRES), Defense Meteorological Satellite Program (DMSP), and Advanced Photovoltaic and Electronics Experiment (APEX).

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1.0 INTRODUCTION

The Institute for Scientific Research (ISR) of Boston College was contracted by the Space Physics Division (GPS) of the Phillips Laboratory (PL) Geophysics Directorate to perform research in the area of Space Particle Modeling and Effects. A number of computer models and simulations were developed by use of the data from various spacecraft including the Combined Release and Radiation Effects Satellite (CRRES), Defense Meteorological Satellite Program (DMSP), and Advanced Photovoltaic and Electronics Experiment (APEX). The CRRES spacecraft is no longer operational; multiple DMSP spacecraft are operational; and the APEX spacecraft was returning limited data at the completion of this contract.

Results from the studies performed on this contract provided a better understanding of the basic physical processes at work in the space environment. Several scientific papers and publications co-authored by ISR personnel resulted from these studies, and a list of the publications and papers is contained in Appendix A.

1.1 CRRES

The CRRES spacecraft was successfully launched into Geosynchronous Transfer Orbit (GTO) on 25 July 1990. The spacecraft orbit had an apogee 33000 km, perigee of 350 km, orbital period of approximately 9 hours and 50 minutes, and an inclination of 18.1 degrees. This orbit resulted in the spacecraft passing through the center of the radiation belt twice per orbit. CRRES carried a compliment of engineering experiments, particle sensors, and sensors designed to obtain wave and field data. The sensor packages allowed for the complete characterization of the radiation belts and the GTO environment.

The CRRES spacecraft sensors operated 24 hours per day. This data was downlinked, processed and a CRRES Time History Data Base generated for each sensor. It is this data base which provided the input for the CRRES related research efforts performed on this contract.

A brief summary of the pertinent CRRES science sensors and the data used for study follows.

AFGL 701-2 SPACE RADIATION DOSIMETER

> The dosimeter consists of four domes which differ in aluminum thickness shielding. The varying thicknesses provide differing electron and proton thresholds. Sensor outputs include accumulated HILET dose, accumulated LOLET dose, star flux, integral HILET flux, integral LOLET flux, HILET dose rate, LOLET dose rate

AFGL 701-4 HIGH ENERGY ELECTRON FLUXMETER (HEEF)

> The solid state spectrometer telescope provides differential flux for 10 electron channels (1-10MeV), and integral flux for 8 proton channels.

AFGL 701-5A MEDIUM ENERGY ELECTRON SPECTROMETER (MEES)

The MEES uses a magnetic field to momentum analyze electrons arriving through an aperture. Differential flux was obtained for 17 electron channels (40keV-2.2MeV).

AFGL 701-5B ELECTRON-PROTON ANGLE SPECTROMETER (EPAS)

This instrument produced electron and proton measurements for a wide range of pitch angles. Sensor outputs consisted of integral flux from 10 electron sensors, integral flux from 4 proton sensors, 14-point differential flux spectra (20keV-250keV) from selectable electron sensors, 12-point differential flux spectra (30keV-20MeV) from selectable proton sensors

AFGL 701-7A RELATIVISTIC PROTON DETECTOR

This sensor was designed to measure energy spectra of relativistic protons trapped in the inner Van Allen belt. There are four sets of 4-point spectra.

AFGL 701-7B PROTON SWITCHES

This instrument consists of two single detector units. Sensor output consisted of proton flux from 2 channels (20-40MeV, 40-80MeV) and star flux from 2 channels.

AFGL 701-8,-9 PROTON TELESCOPE (PROTEL)

The PROTEL produced differential flux for a 24-point proton spectra (1-100MeV).

AFGL 701-11A MAGNETOSPHERIC ION COMPOSITION SENSOR (MICS)

When operated in normal mode, 8 m/q values were selected for energy analysis (nominally 30 keV/g to 400 keV/q) and a 32-point energy spectrum produced; in auroral mode, 8 m/q values are selected and a 16-point energy spectrum is produced at double the data rate of normal mode. Typical values of m/q included H+, He+, He++, O+ and O++.

ONR-307-8-3 MEDIUM ENERGY ION MASS SPECTROMETER (IMS-HI)

This sensor was commandable into any of three operating modes.

LOCK MODE (mass mode) - For 4 fixed (commandable) masses, 6-point differential flux ion spectra and a neutral read out were obtained. The energy range of the spectra varied with mass, e.g., H+ was approximately 30 keV to 2.5 MeV; He+ was approximately 7 keV to 1 MeV.

SWEEP MODE (energy mode) - 64-point mass spectra at 7 energies.

SWEEP-LOCK (energy-mass) - alternated between sweep and lock on a periodic basis.

1.2 DMSP

The Defense Meteorological Satellite Program (DMSP) spacecraft have been launched since the early 1960's. Several of these polar orbiting satellites have been successfully launched and vast amounts of data exist for further analysis. Normally, there are two DMSP vehicles in operation at any given time, each with a planned lifetime in orbit of three years. They are both in sun-synchronous orbits with one operating in the dawn-dusk meridian plane (0600: to 1800:) and the other in the meridian plane covering approximately 1030: to 2230:. The altitude of these vehicles is 835-840 kilometers (circular) which results in an orbital period of approximately 101 minutes. The vehicles are non-spinning with the vehicle +X axis pointing vertically to earth throughout the orbit. Momentum wheels located within the spacecraft are used to maintain the desired attitude.

The PL/GPS Particle Spectrometer (SSJ4) and Dosimeter (similar to that flown on CRRES) provided the main data source for studies performed on this contract.

1.3 APEX

The Photovoltaic Array Space Power Plus Diagnostics Experiment (PASP-Plus) was designed to characterize the high-voltage electrical performance of a set of advanced solar arrays operating in the natural space environment, characterize the long-term radiation degradation effects of these solar arrays, determine the impact of the space environment on solar array operation, and flight qualify certain advanced solar array designs.

The experiment consisted of various solar array modules and a complement of diagnostic sensors to measure array performance and evaluate the space environment.

SOLAR ARRAYS

> Sixteen solar arrays are electrically monitored. Some undergo high-voltage biasing to evaluate their potential application under these high-voltage conditions. Current vs. voltage (I-V) curves are generated and the results are analyzed and correlated with data from the on-board environmental diagnostic sensors.

DOSIMETER

> The PASP Plus Dosimeter measures the short- and long-term particle radiation that damages solar cells by separately measuring the total accumulated radiation dose due to electrons and protons, separately measuring the electron and proton particle fluxes, and measuring large energy deposition events (possible single event upsets (SEUs)).

SPACECRAFT HOUSEKEEPING

> The spacecraft housekeeping instrumentation contained electronics used for the monitoring of Single Event Upsets (SEU). This data was downlinked as part of the overall housekeeping data set.

2.0 DMSP SSJ4 MIDNIGHT BOUNDARY INDEX

The DMSP SSJ4 data has been used to generate the Midnight Boundary Index which is an estimate of the equatorward boundary of precipitating auroral electrons.

An algorithm for the determination of the midnight boundary has been developed. The prime input for the algorithm is the electron data gathered from the SSJ3 (F2 and F4 satellites) and SSJ4 (F6 to F13 satellites) particle detectors flown aboard the DMSP satellites. The period covered runs from the end of 1977 until the present.

It has been shown that the variation in the latitude of the outer edge of the auroral oval that can be detected with the algorithm correlates quite well with current magnetic activity indices such as Kp. This relationship can be used to calculate a near-real-time magnetic activity index, or a 'provisional' Kp.

More information on this and a selection of current displays have been made available on the world wide web (www) with the following address:

http://www.plh.af.mil/gps/dmspssj4_midnit.html

Midnight Boundary data are available via anonymous ftp from node ph4000.plh.af.mil in directory [.DMSP]

Figure 1 is a display of the boundary algorithm www page. One of the selectable midnight boundary displays from this page is contained in Figure 2.

Since 1992, there have been a number of modifications made in procedures and techniques used in the determination of an equivalent midnight boundary index. The modifications can be broken down into the following three categories:

1) Software maintenance
2) Quality Flag
3) Final Format, Display and List

SOFTWARE MAINTENANCE

All boundary determinations made available before 1991 were generated using the PL Central Site CDC-NOS operating system reading specifically formatted 9-track tapes. The current source code remains in FORTRAN, but it has been re-hosted on a UNIX operating system. There have been fundamental changes made in the code as well as the input data formats and media type. Software and script files were developed for the new data interface. Through further enhancements, the user is allowed to run up to one year's worth of satellite data within a single job execution from either the UNIX mainframe's mass storage device (UNITREE) or the UNIX workstation's (NASHOBA) CD-ROM.

Since the previously mentioned software update has been completed, boundaries have been generated from the data for F10, F11, F12 and now F13. In the past, boundaries had been

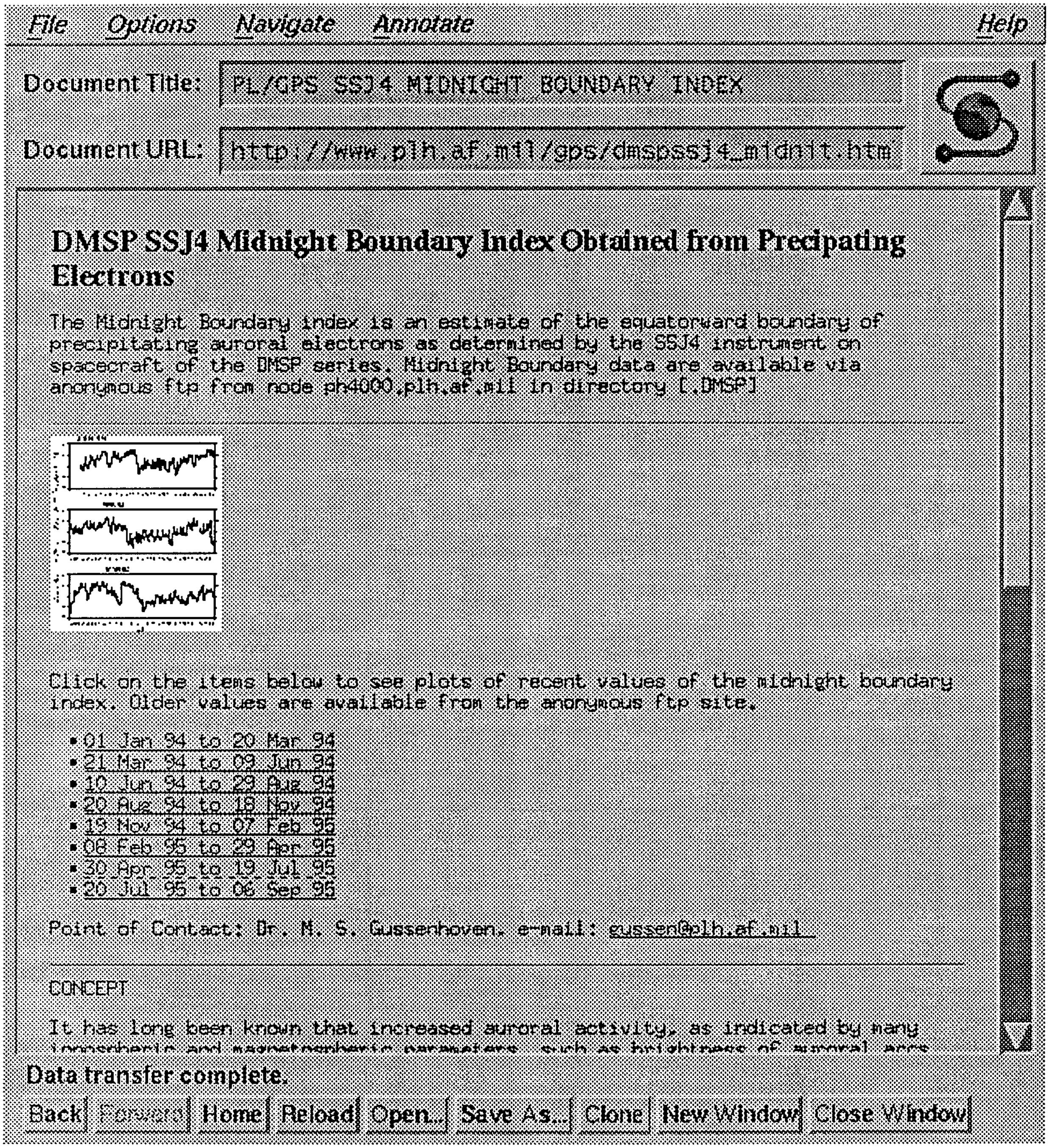

Figure 1 - Boundary Index Home Page on www

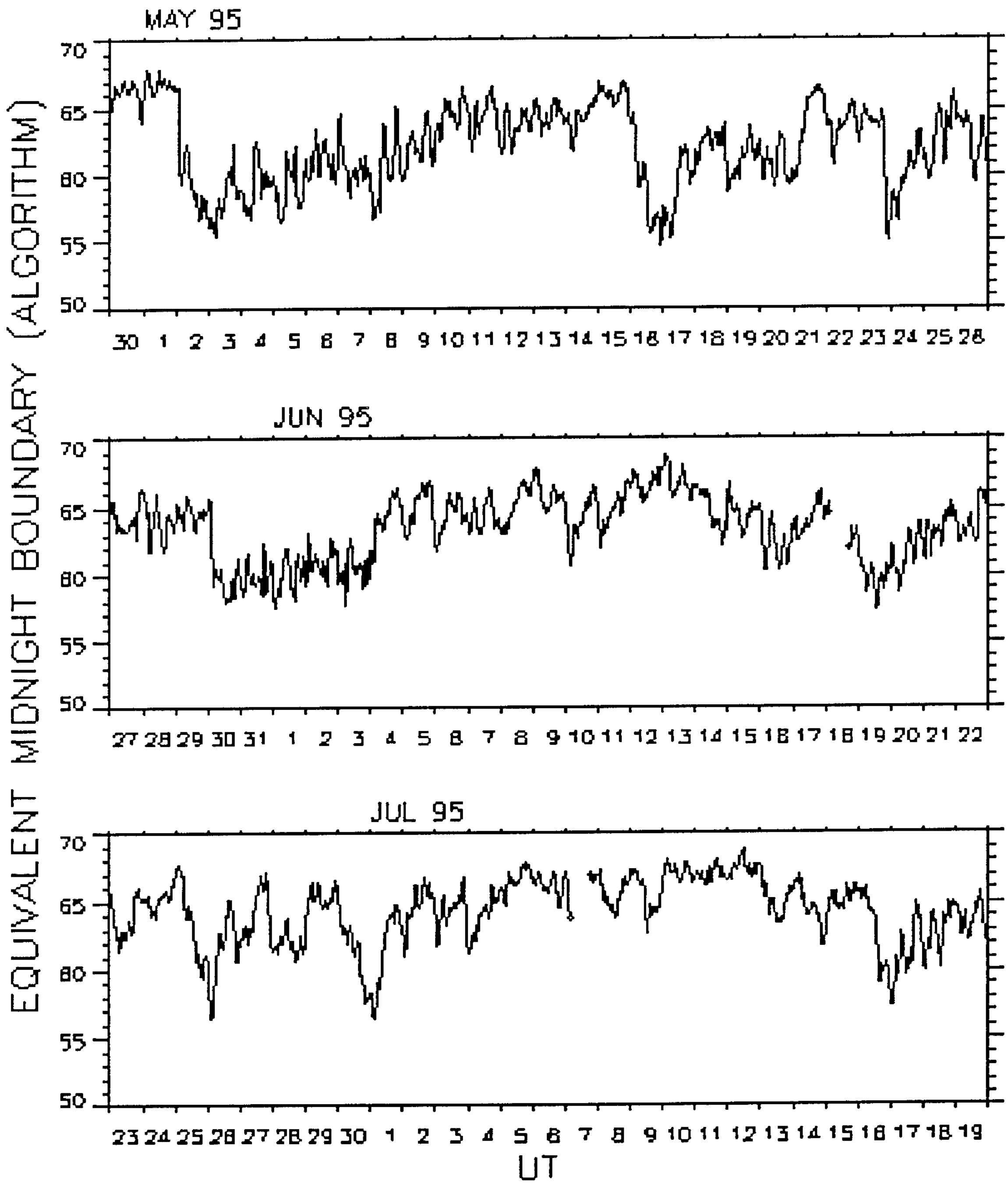

Figure 2 - Auroral Boundary Index

generated for F10 and F11 using the NOS/VE operating system, but in order to maintain a consistent computing platform for the hosting of the data, the boundaries were re-generated on the Unix system. Each satellite has unique count-rates in energy channels that are involved in the algorithm selection, so data from each new satellite must be carefully analyzed in order to provide the algorithm with a unique set of constants for the channels involved. Boston College personnel have been heavily involved in this key area of analysis since it is essential to the determination of proper boundaries. A number of data visualization routines have been developed to analyze and interpret the J4 data for these needs.

QUALITY FLAG

Personnel from the 50th Weather Squadron have need of the boundary selections in real time to determine provisional Kp as part of their space forecasting system. Occasionally, an inaccurate boundary value is determined and, as a result, a request was made for a 'quality flag' that would assist in their data interpretation. Previous documentation suggest that narrowing the MLT range of accepted boundaries would result in getting approximately 98 percent reliability at the expense of using only about 1/3rd of the possible boundary selections. On average, there are 57 possible boundaries crossed by each satellite each day. Assuming a minimum of two operational satellites at any given time, (anywhere from two to four since F7) there would be on the order of 40 selections a day. In general, this has been the accepted method of enhancing the accuracy of the boundaries for graphical displays.

Although using hourly regression values for local time to compute the equivalent midnight boundary is proper, as is using the correlation coefficients to determine bad MLT areas (anywhere around noon) , it has become apparent that there are other influences that could have effects on the probability of a proper boundary selection. Satellite orbit, season, and longitude can account for increases in contamination in the detectors that could alter or make impossible a boundary selection.

All satellite data from 1991 until the middle of 1995 were merged in chronological order to form one composite data set. Using this data set, a number of tables were generated that would suggest that for a given satellite (F6=1, , , F13=8), pole (1=north, 2=south), season (1=winter, , , 4= fall), longitude (1=0 to 90, , , 4=270 to 360) and of course MLT (1=0 to 1, , , 24=23 to 24), the selected boundary would be +/- X-sigma from the average of the surrounding N boundaries. Through extensive effort and a number of test runs, the following numbers were determined and used : N = 27 and X = 1.5

To synopsize the analysis, for every 27 points, a running average was computed along with a standard deviation. If the 14th point (middle) was within the Average +/- Sigma x 1.5, it was considered a reasonable selection and tallied in an array with indices that correspond to the previously mentioned parameters. Once this is done, the first point is dropped out and the next point is added to the end and the process is continued until the end of the data set. This then permits the tables to be calculated and listed as a text file which will later serve as a lookup table. Another calculation, which is performed at this time, is to combine all tables, by satellite, to make another table that can be used as a provisional table for a 'new' satellite, such as F13 (until enough boundary selections are available). Another statistics file that is produced lists the percentage value from high to low from each satellite's look-up table and the corresponding percentage of all the boundaries of that satellite that would meet that percentage and higher. In other words, it will let the analyst know what percent value to use as a cutoff in order to look at the top third of the boundaries. This is also done with the

provisional table.

Table 1 shows the formatted percentages of the F10 look up table for the longitude bin of 0-90. There are three other similar tables for the other longitude bins. Just as for F10, each of the satellites has its own four tables. Table 2 shows the 'provisional' table for the same latitude bin as Table 1.

Figure 3 is a display from one of the graphics packages that was used to look at the boundary selection algorithm for new satellites and compare it to count rates, and to show how a selected boundary can compute a flag and provisional Kp. The look-up tables were accessed much like they will be in real time, as the boundary was calculated.

Figure 4 is another display from one of the graphics packages which permits the user to 'fine tune' flags 1, 2, and 3 based on percentages from the look-up table.

Ultimately, the 50th Weather Squadron will get, with a boundary selection, a flag of 1, 2, 3 or -1. A flag of -1 means that there was not a boundary determination and that the returned value should be ignored. Flag 1 means that of all the determined boundaries, this is in the top third for reliability. Flag 2 and 3 are respectively the next two thirds. It varies slightly for each satellite, but flag 1 has about a 95 percent reliability, flag 2 about 90 percent and flag 3 about 75 percent.

An Interactive Data Language (IDL) routine was developed which displays Flag 1 selections in a solar rotation format, five plots per page. A complete set of data from 1983 to present (35 plots) can be printed out in postscript for PL/GPS usage on request. Figure (4) is a bitmap taken from the screen of one of these plots.

FINAL FORMAT, DISPLAY and LIST

Some of the PL/GPS scientists who are using the boundary data to drive their magnetic field models have observed occasional 'chatter' in Flag 1. This refers to the variation of a few degrees between consecutive boundaries. This variation is quite apparent in Figures 4 and 5. Although the cause has never been fully determined, the boundary algorithm itself has been examined many times for improvement in this area. To alleviate the 'chatter', a data set has been produced that consists of a four-point running average of all the flag 1 data. This results in minimal chatter without wiping out all of the finer structure. The same IDL routine used to generate the displays that includes Figure 5 is also available for this data set and a set of plots also exist for printing in postscript. Figure 6 is the same plot as Figure 5, except that it uses the smoothed data. Figure 2, which is found on the WWW, is also a product of the smoothed data.

F-10 SATELLITE   GEOMAGNETIC LONGITUDE (0 TO 90)

	NORTH POLE				SOUTH POLE				
MLT	W	SP	SU	F	W	SP	SU	F	– SEASONS
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
4	0.0	0.0	0.0	0.0	89.3	83.3	0.0	0.0	
5	0.0	0.0	0.0	0.0	91.7	89.3	89.9	85.4	
6	0.0	0.0	0.0	0.0	89.8	92.9	90.5	89.5	
7	0.0	0.0	0.0	0.0	94.0	90.6	92.6	93.8	
8	0.0	0.0	0.0	0.0	92.4	88.0	90.8	94.6	
9	0.0	0.0	0.0	0.0	0.0	100.0	93.9	0.0	
10	95.2	89.3	82.1	94.4	0.0	0.0	0.0	0.0	
11	79.2	84.1	67.8	89.0	0.0	0.0	0.0	0.0	
12	71.6	75.8	65.7	62.6	0.0	0.0	0.0	0.0	
13	50.5	54.0	56.7	52.2	0.0	0.0	0.0	0.0	
14	75.7	87.8	82.9	82.1	0.0	0.0	0.0	0.0	
15	97.3	0.0	0.0	100.0	0.0	0.0	0.0	0.0	
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
18	100.0	98.4	100.0	0.0	0.0	0.0	0.0	0.0	
19	99.2	96.4	96.7	98.9	97.2	97.3	96.6	0.0	
20	96.0	97.4	98.8	97.4	99.7	97.6	96.0	98.1	
21	96.0	98.2	98.6	97.0	98.0	97.8	98.0	98.2	
22	97.9	97.8	99.6	96.6	97.5	98.3	98.5	96.6	
23	0.0	0.0	100.0	0.0	88.2	92.6	93.3	90.4	
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

TABLE (1)

PROVISIONAL TABLE   GEOMAGNETIC LONGITUDE (0 TO 90)

	NORTH POLE				SOUTH POLE				
MLT	W	SP	SU	F	W	SP	SU	F	– SEASON
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2	0.0	0.0	0.0	0.0	94.7	93.6	92.5	84.4	
3	0.0	0.0	0.0	0.0	96.8	93.3	93.5	93.8	
4	0.0	0.0	0.0	0.0	92.3	89.6	96.7	96.0	
5	98.3	97.8	100.0	86.2	93.2	91.1	94.4	92.7	
6	94.7	95.9	97.6	94.9	91.1	93.1	92.6	91.8	
7	98.5	94.7	86.0	97.4	88.1	91.5	92.7	93.5	
8	85.0	91.1	98.1	94.4	91.2	88.0	92.9	94.5	
9	77.9	79.9	90.2	87.2	90.4	93.3	91.4	93.0	
10	75.9	73.7	82.1	76.1	69.9	80.0	83.3	76.5	
11	79.2	84.1	67.8	89.0	0.0	0.0	0.0	0.0	
12	71.6	75.8	65.7	62.6	0.0	0.0	0.0	0.0	
13	50.5	54.0	56.7	52.2	0.0	0.0	0.0	0.0	
14	75.7	88.0	87.1	82.1	100.0	86.2	88.4	95.0	
15	94.0	93.8	93.5	97.4	79.6	77.9	83.5	87.2	
16	94.0	95.8	94.5	96.2	92.2	90.6	91.9	90.2	
17	94.4	95.0	94.2	93.3	94.5	89.0	93.9	95.4	
18	97.8	96.4	95.1	95.4	96.9	97.2	93.5	98.7	
19	99.2	96.4	96.7	98.9	98.9	98.6	97.4	95.4	
20	91.2	95.1	97.5	94.7	99.1	98.4	97.3	94.6	
21	97.7	98.9	99.3	98.2	98.0	97.8	99.0	98.2	
22	98.0	98.9	99.8	98.3	97.5	98.3	98.5	96.6	
23	98.6	98.6	99.5	100.0	88.2	92.6	93.3	90.4	

TABLE (2)

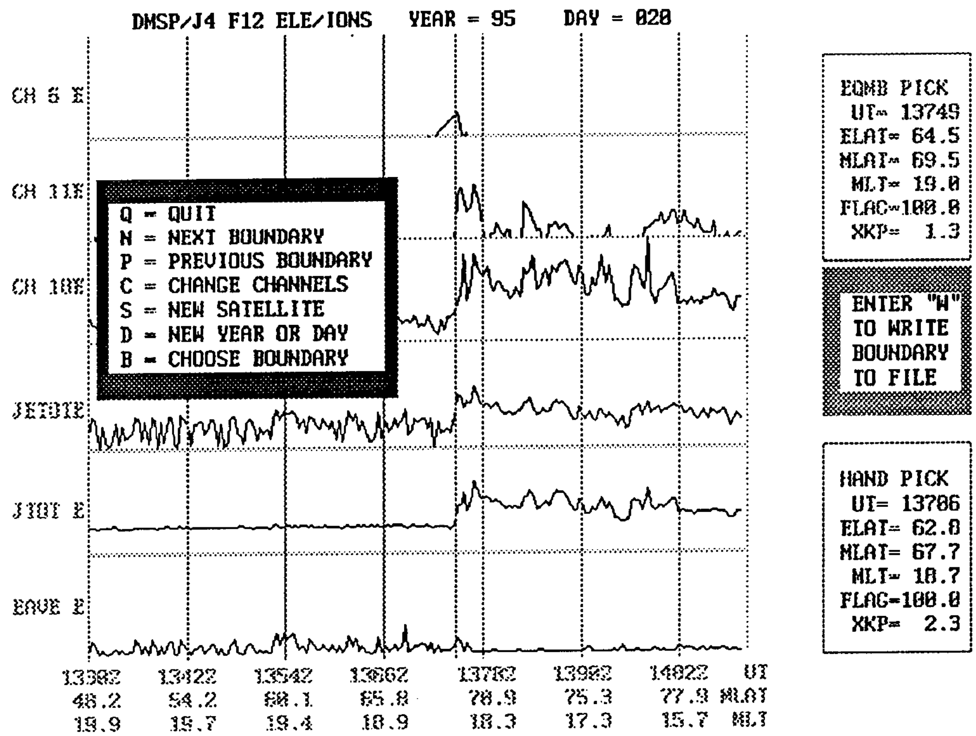

Figure 3- Boundary Algorithm Determination Graphic

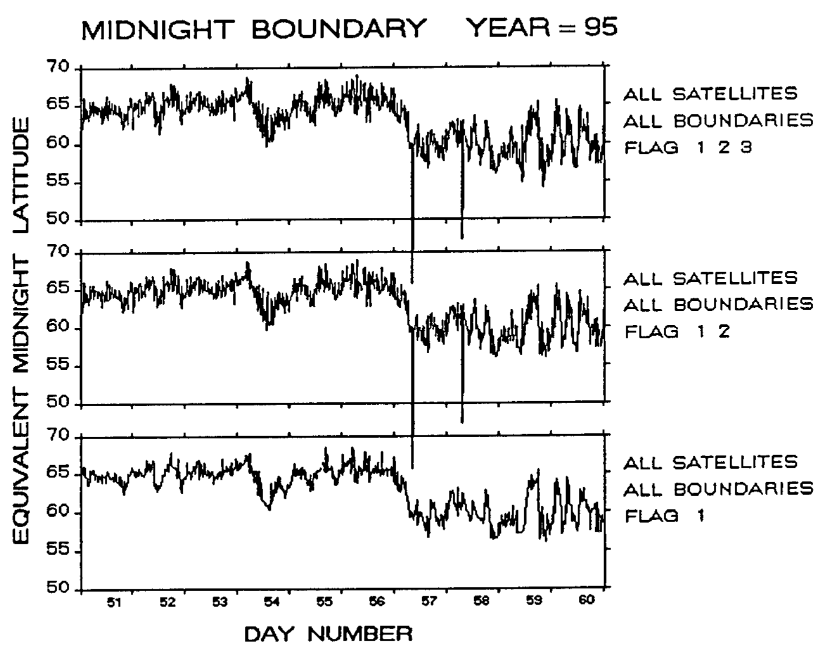

Figure 4 - Boundary Algorithm Display

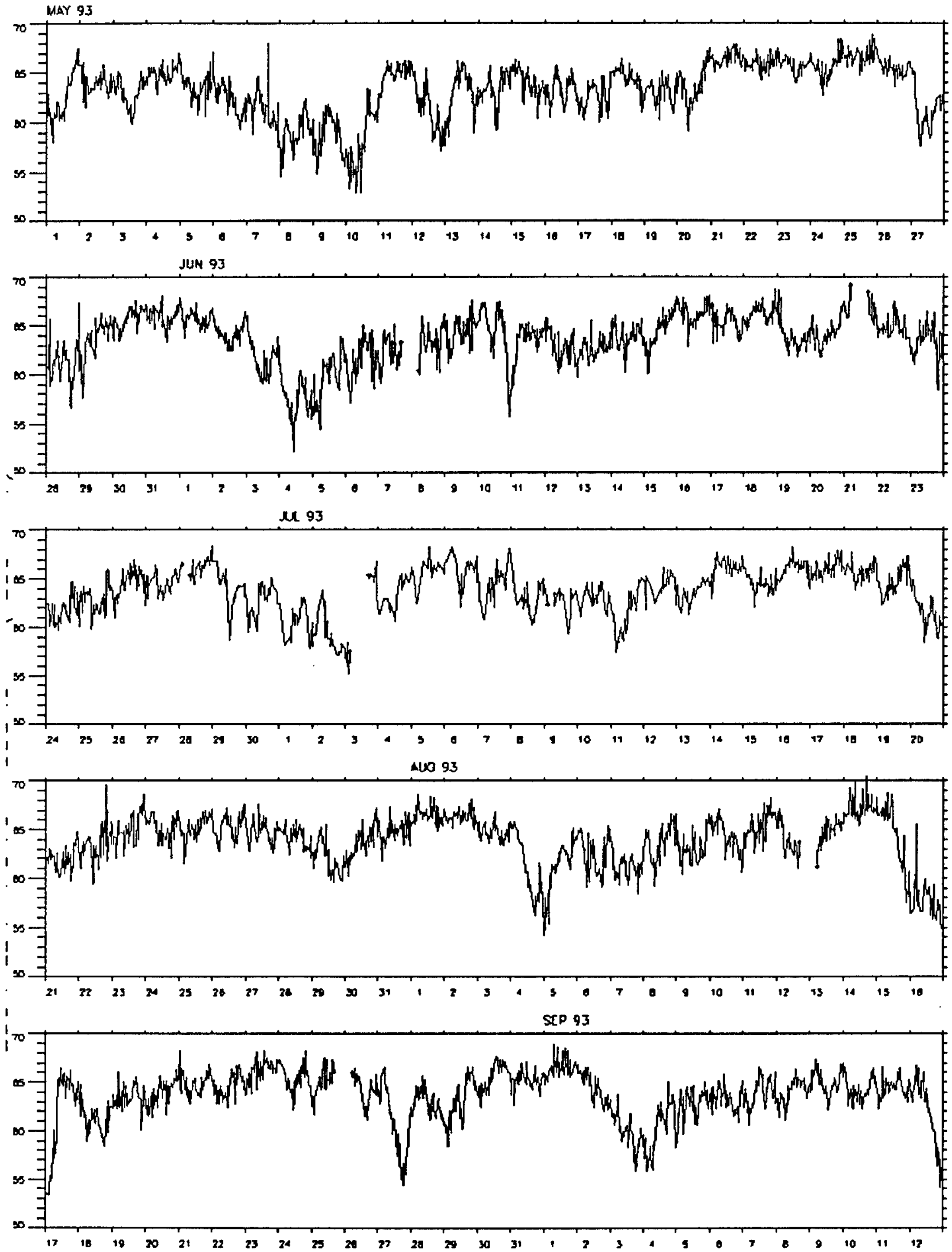

Figure 5- Boundary Algorithm Display

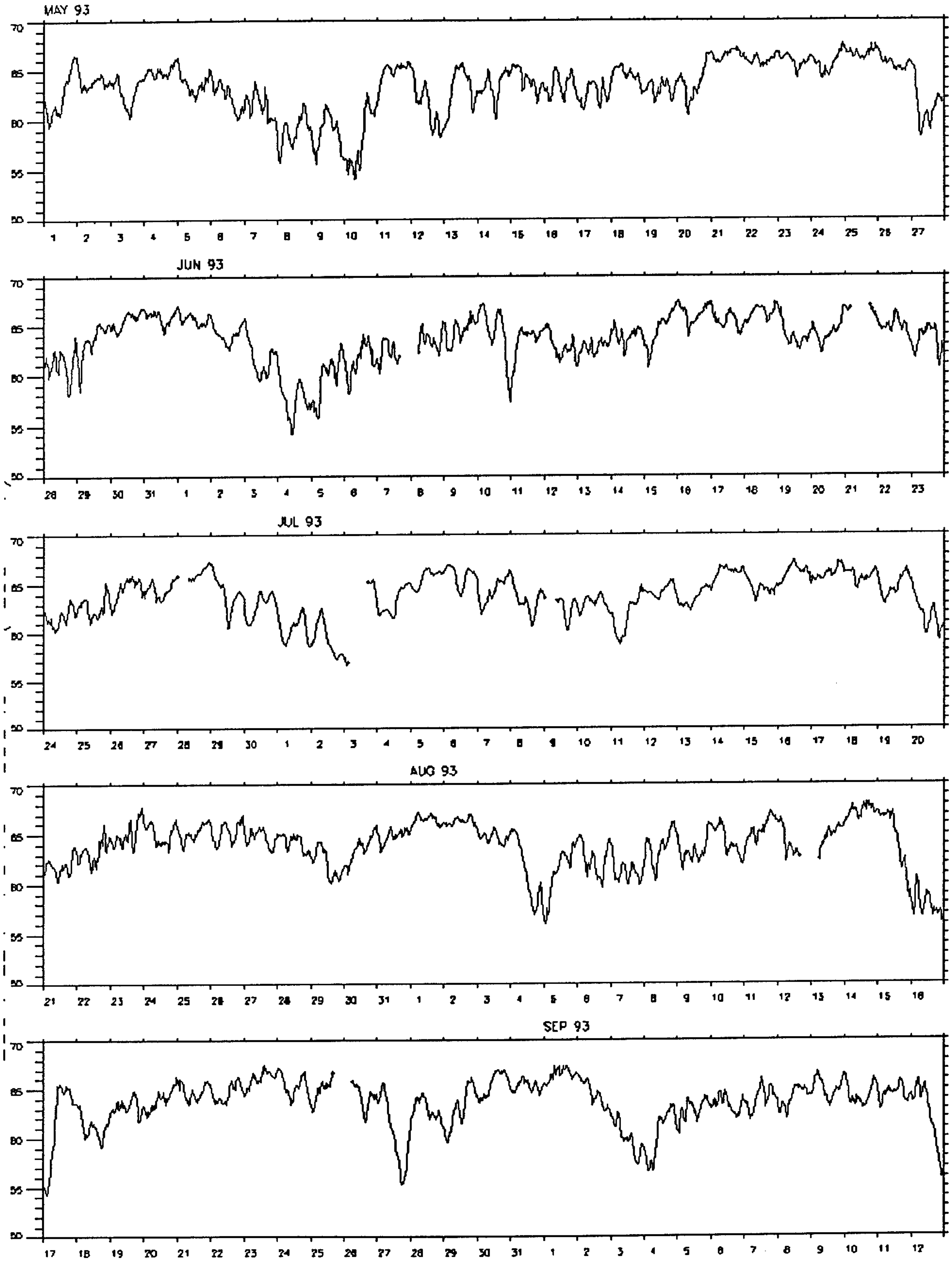

Figure 6 - Boundary Variation - Smoothed

3.0 DMSP J4

The J4 electron and ion sensors flown on the Defense Meteorological Satellite Program spacecraft were designed to measure electrons and ions from a few tens of eV up to 30 keV. The DMSP J4 particle sensors have provided a wealth of data in this energy range over the last two decades which has been used extensively for scientific investigations and near-real time space weather forecasting at GPSP. Boston College, under this contract, has had the primary responsibility for all data processing, development of analysis and visualization software for the J4 data, and for quality control and archiving of all the data.

One of the initial goals for this part of the DMSP project was to generate and maintain a database containing all available DMSP J4 data, as a near real-time database (within 30 days of current), to make access to the data independent of magnetic tape, and to migrate the databases to local media (optical and cd-rom) that is accessible to GPS computers. This goal was met under this contract.

All available data was defined to be all data since day 228 of 1986 for full orbit data and all available F6 and F7 high-latitude data for the period prior to that. One-day data files were generated from DMSP archives for all data existing prior to the beginning of this contract. New data was processed and added to the database. The primary database consists of over 10857 one-day files, all or part of 39 satellite years of DMSP J4 data for satellites F6 through F13 and spanning the period of 1982 through 1995.

The primary data base exists as binary files with fixed length records, each containing data from one full day of a DMSP satellite. Its permanent location is the UNITREE system on the central site CD4360 computer. The actual storage media is exabyte tape cartridges; two copies of each file are kept as part of the UNITREE system. In addition, the one-day files are grouped into sets of 25 files, compressed and put into archive form using the standard UNIX compress and tar utilities. These are also saved under UNITREE, giving a total of four copies of all J4 data on line. With this redundancy factor, the database is secure. One additional copy of the 25-day files is made to CD-ROM giving a final redundancy factor of five. The entire database in its compressed form fits onto thirty CD-ROM disks.

Each of the one-day files is processed and summary information from it is computed and added to a series of one-year random access files. There are four sets of these files and they form a secondary database which becomes the input to a series of visualization routines and other end-product applications. The first of these is with data binned by magnetic latitude with a background correction. The second is with data binned by McIlwains L parameter, also corrected for background. The other two are with no background correction. Each of the four sorts is divided into four logical quadrants, the first being the 90 degree sector in magnetic longitude centered on the South Atlantic Anomaly, the third a 90 degree sector 180 degrees from that, the second quadrant consisting of dayside particles (12 hours in Magnetic Local Time centered at local noon, and the fourth 12 hours centered at local midnight. The two magnetic latitude sorted sets are maintained for all satellites (a total of 39 files through 1995) and the L sorted sets are maintained for one or two selected satellites for each year in order to give complete time coverage.

The active part of the secondary database (only the current year is necessary) is stored on the GPS Silicon Graphics (SGI) NASHOBA workstation, and the remainder stored on UNITREE exabyte. These have been further processed to generate a set of end-product data files, optimized for the display routines, and they reside on GPSSERVER for the background corrected files and on AMENRA optical stack for the uncorrected. The one-year and end-product files sets are complete with all data available at the end of this contract processed.

Application packages have been developed for the J4 data set to produce end-products. These include:

a) Data base interface: The first is a Unix script interface to manage the 25-day tar files and deliver one-day files to the end user for special applications. The end user is defined to be anyone needing access with an account on any of the Unix or VMS mainframes, any Unix workstation or any PC (386 or above with numeric coprocessor) with PC\FTP or PathWorks installed. A full set of interface routines was developed for accessing the data stored on either Unitree or CD-ROM. They have been fully tested from UNIX, VMS, and the PC.

b) Satellite-year display: The second package is a color spectrogram viewer for the satellite-year end-product files in the secondary database. It is a 16-color display of one day averages of J4 data with the x-axis for the day of year and the y-axis either magnetic latitude or McIlwain's L shell parameter, depending on what is in the end-product file. Varying colors then designate count rate levels.

   The default display from this application is the "High Energy Electron Display". It is the display of channel one of the J4 electron sensor and is routinely used to monitor the two to five MeV electrons which appear as background in all the energy channels. Channel one is routinely chosen for this purpose since the real 30 keV electron count rates are small relative to the other channels.

c) Composite display: The third generates a multi-year composite color spectrogram. By default, it displays the entire period between day 362 of 1982 to the present with a selected subset of the eight available satellites spanning that interval for channel one of the J4 electron detector. The default satellite set is F6, F8, F11, and F13 and the composite of those four satellites gives continuous coverage for the fourteen year period. Since visual continuity was of greater concern for this application than absolute count rates, data from the four heads of each instrument were normalized to the corresponding one on F8. The primary purpose of this application is to display and study two to five Mev penetrating particles on a solar cycle time scale.

d) Satellite display: The fourth generates a satellite level color spectrogram. It is similar in construction to the above applications, but merges all the years of a selected satellite into one display. Its primary purpose is to monitor effects that are specific to an individual satellite, such as noisy channels and sun-glint background effects and it is used as a quality control tool.

e) Orbital display: The fifth generates a half screen color spectrogram with data displayed as Energy vs. time for each orbit for either electrons or ions. The other half screen normally displays five separate 12-second averaged spectra as linear plots; however, it can display a subset of the corresponding SSIES data if it is available.

Items b) through d) were designed to share a common set of application data files, the end-product component of the secondary database. They have the same menu, keyboard, and mouse interfaces where applicable. The composite does not have a data selection menu, but does have provisions for substituting any satellite-year for the default one from the keyboard interface. They also have provisions to automatically retain X-, Y-, and color scales information from the user's last access. An automenu interface has been installed on most of the GPSP PCs for all applications.

4.0 RADIATION BELT MODELING

A number of efforts were performed with respect to radiation belt model studies which used both CRRESRAD and CRRESPRO analysis packages and input information from the CRRES data set. Later, studies with the 'inner' belt involved data from the CRRES, DMSP and APEX dosimeters (see, 'Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite).

The CRRESPRO used the PROTEL data base and the CRRESRAD used the DOSIMETER data base. The models used individual orbit files that have been sorted by 1/20th of an L-shell, leg, and 5-degree pitch angle bins. In the case of CRRESRAD, the data was binned in 28 B/B0 bins instead of 19 five-degree pitch-angle bins. It is these individual orbit files that have been used as the basis for a number of displays and studies. Other instruments were processed the same way. In particular, HEEF, EPAS and MEA, were used. Data from other CRRES sensors was similarly binned. The binning process is described in a later chapter. In all cases, the same file structures were generated using a suite of tailored library routines.

Some software was in place as CRRES flew in 1990 to 1991, but due to changes in operating systems and storage devices it was necessary to transport all the data to new media and re-write analysis code and procedures used to generate appropriate data sets. There were a number of data visualization packages developed for the viewing and analysis of pertinent files.

The volume of satellite data available at PL/GPS permitted the detailed study of data from a single sensor as well as comparative studies of similar data sets from different spacecraft. By developing systematic and generic procedures for each spacecraft, these analysis efforts were performed in a highly cost effective manner. Should data from future spacecraft become available, the same techniques will be applied and detailed studies and correlations performed to further enhance the knowledge base in the radiation belt regions.

With APEX-PASP dosimeter data becoming available in 1994, a study to compare the inner edge of the radiation belt over a solar cycle was initiated. The major difference in the models was to bin by 1/100th of an l-shell instead of 1/20th and have 90 B/B0 bins instead of 28. This made for much more detailed plots.

Figure 7 shows the delta dose models for HILET for the PASP dosimeter.

Figure 8 shows the solar cycle comparison of the inner edge from three different satellites.

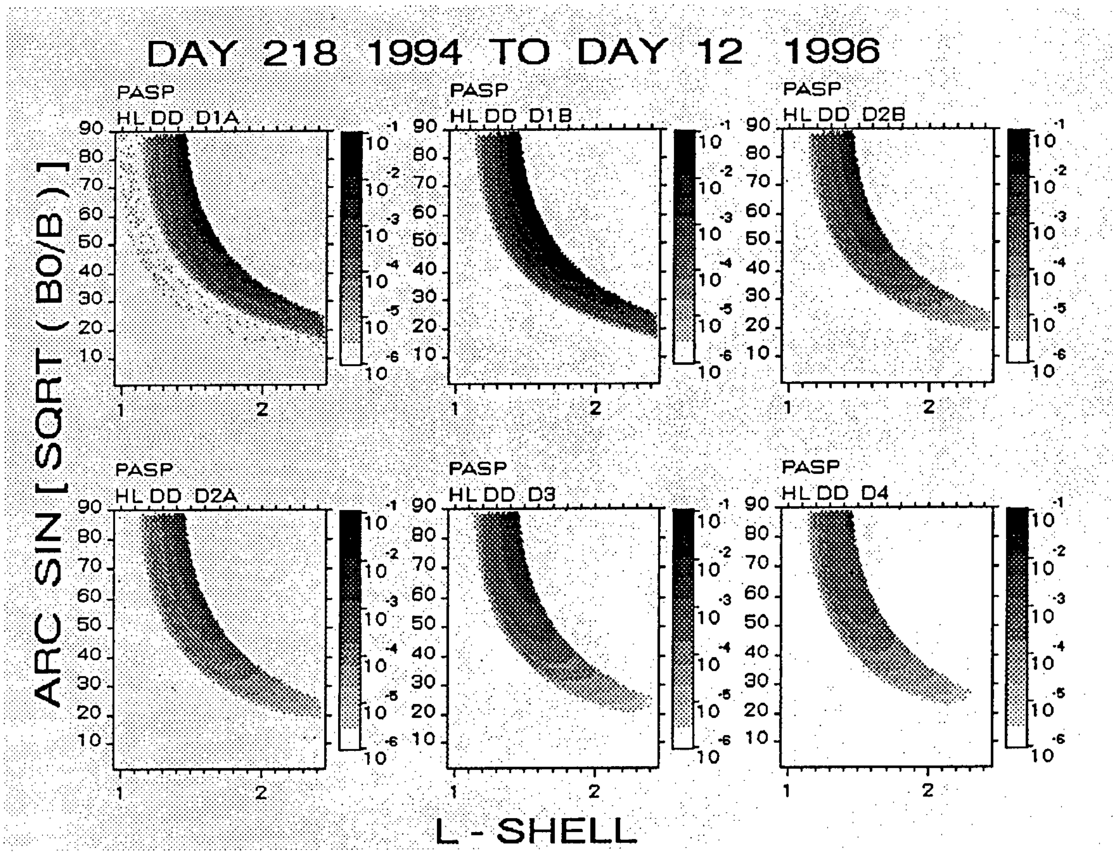

Figure 7- PASP+ Dosimeter Data

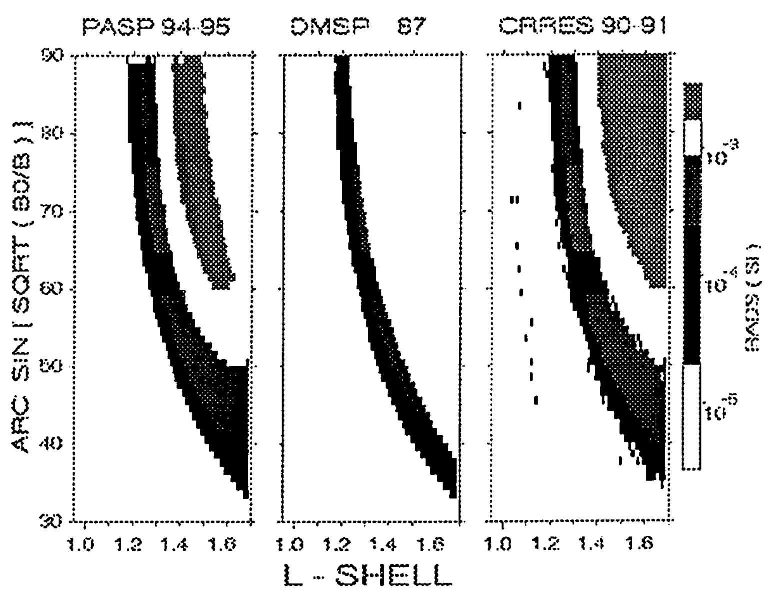

Figure 8 - Multi-spacecraft Dosimeter Correlation

5.0 SINGLE EVENT UPSETS - APEX

On-board data storage for orbital spacecraft has transitioned from the mechanical tape recorder to solid state data recorders. Since these devices are operating in the harsh space radiation environment, single event upsets (SEUs) can occur and thus result in anomalous behavior. A number of past studies were performed on SEUs, but the APEX spacecraft provided an opportunity for detailed study. The spacecraft provided a unique opportunity for SEU study since it flew deep into the proton radiation belt and the payload included a dosimeter, the output of which was used in correlation with the SEU data. The results of the studies were published by Mullen et al (SEU Results from the Advanced Photovoltaic and Electronics Experiment (APEX) Satellite) - see appendix. Hence, this section will touch briefly on the preparation of the data.

The APEX spacecraft carried 176 DRAMs which were monitored for SEUs and corrected with Error Detection and Correction (EDAC) codes. The SEU data was transmitted from the spacecraft as part of the standard housekeeping file.

Figure 9 represents a full day (95075) of the raw SEU data as transmitted from the spacecraft. For each SEU detected, the SEU counter was increment by 1. The fixed word length (1 byte) counter containing the SEU information would 'roll over' at 255 counts. The raw counts were converted to SEU/Min by using delta time/delta counts techniques which accounted for 'roll overs', time lags, dropout, and noise. The result of the conversion from the raw SEU state to SEU/Min is displayed in Figure 10.

An SEU database for days 3 Aug 94-29 Sep 94 and 16 Mar 95-16 May 95 was then generated which contained merged ephemeris and magnetic parameters. This database contained the historical SEU data set. The data was then binned by L-Shell using the standard binning procedures developed for other sensors and spacecraft. The Dosimeter data, which had been binned using the same binning procedures was then merged. This provided the complete L-Shell binned data set for final studies.

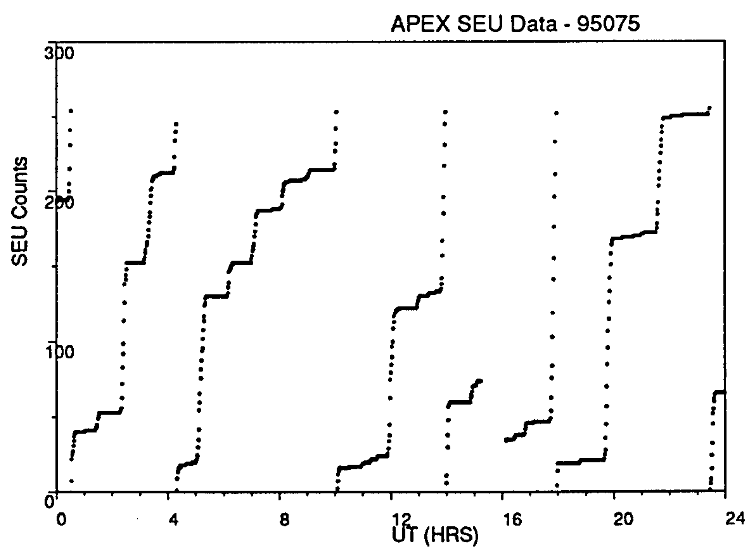

Figure 9 - APEX Raw SEU Data

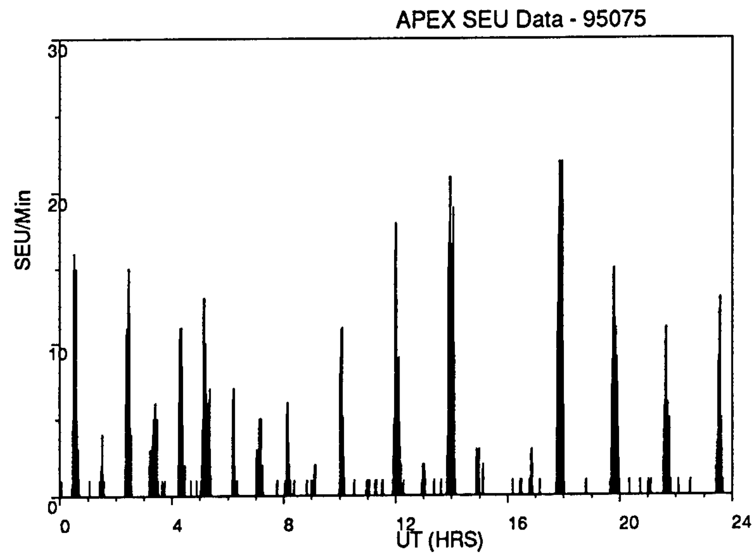

Figure 10 - APEX SEU/Min

The total number of SEU occurrences in each L-Shell bin was computed and the results of these determinations are reflected in Figure 11.

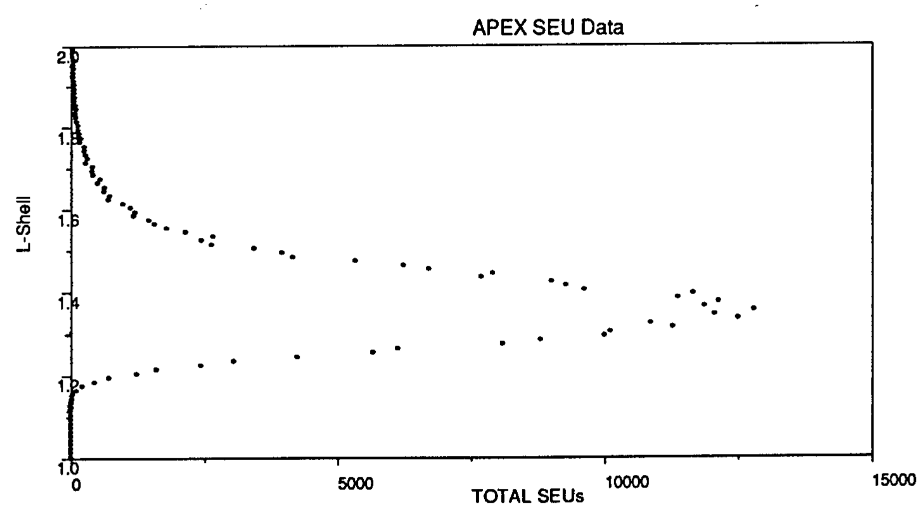

Figure 11 - L-Shell Distribution of APEX SEUs

The SEU/Min data was correlated with each of the Dosimeter channels to determine the best fit between the two sets of parameters. Correlation coefficients were computed to determine the best match.

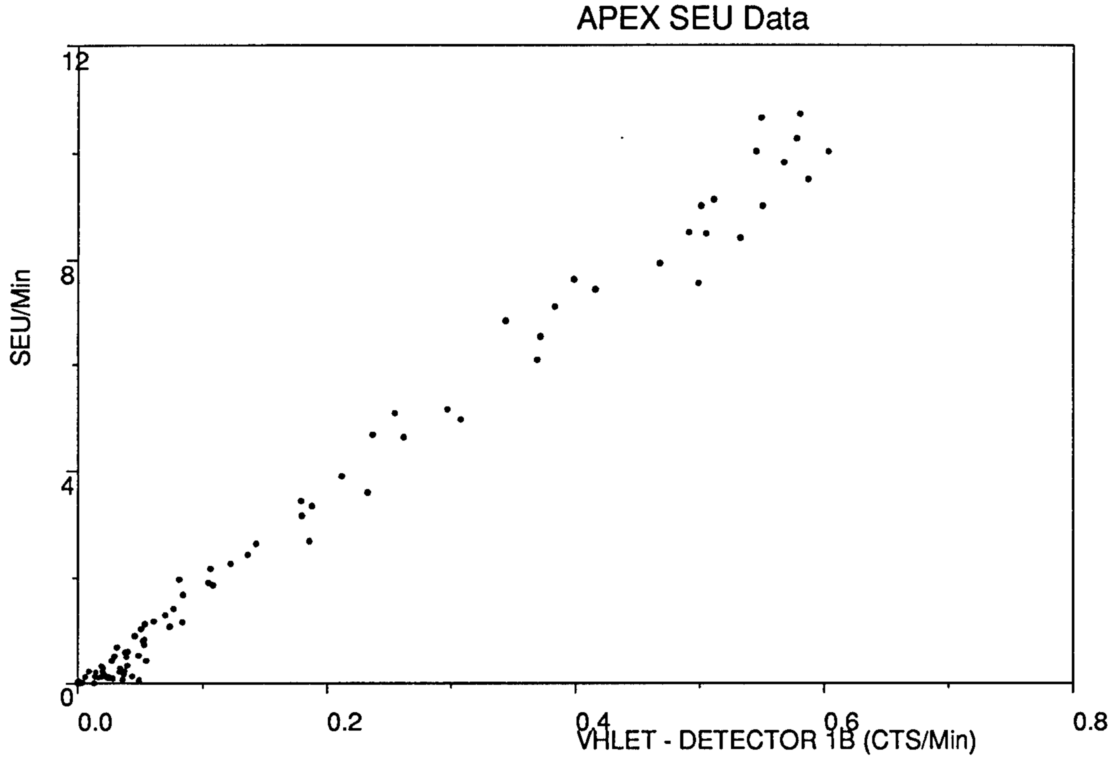

Figure 12 - SEU / Dosimeter Correlation

The SEU data were binned in terms of latitude and longitude and displayed in discrete 100km altitude bins. Figure 13 reflects the SEU data from near the heart of the inner radiation belt down to lower altitudes. The lowest of the three altitudes displayed (800-900km) shows a dramatic reduction in SEUs except for the area of the South Atlantic Anomaly (SAA).

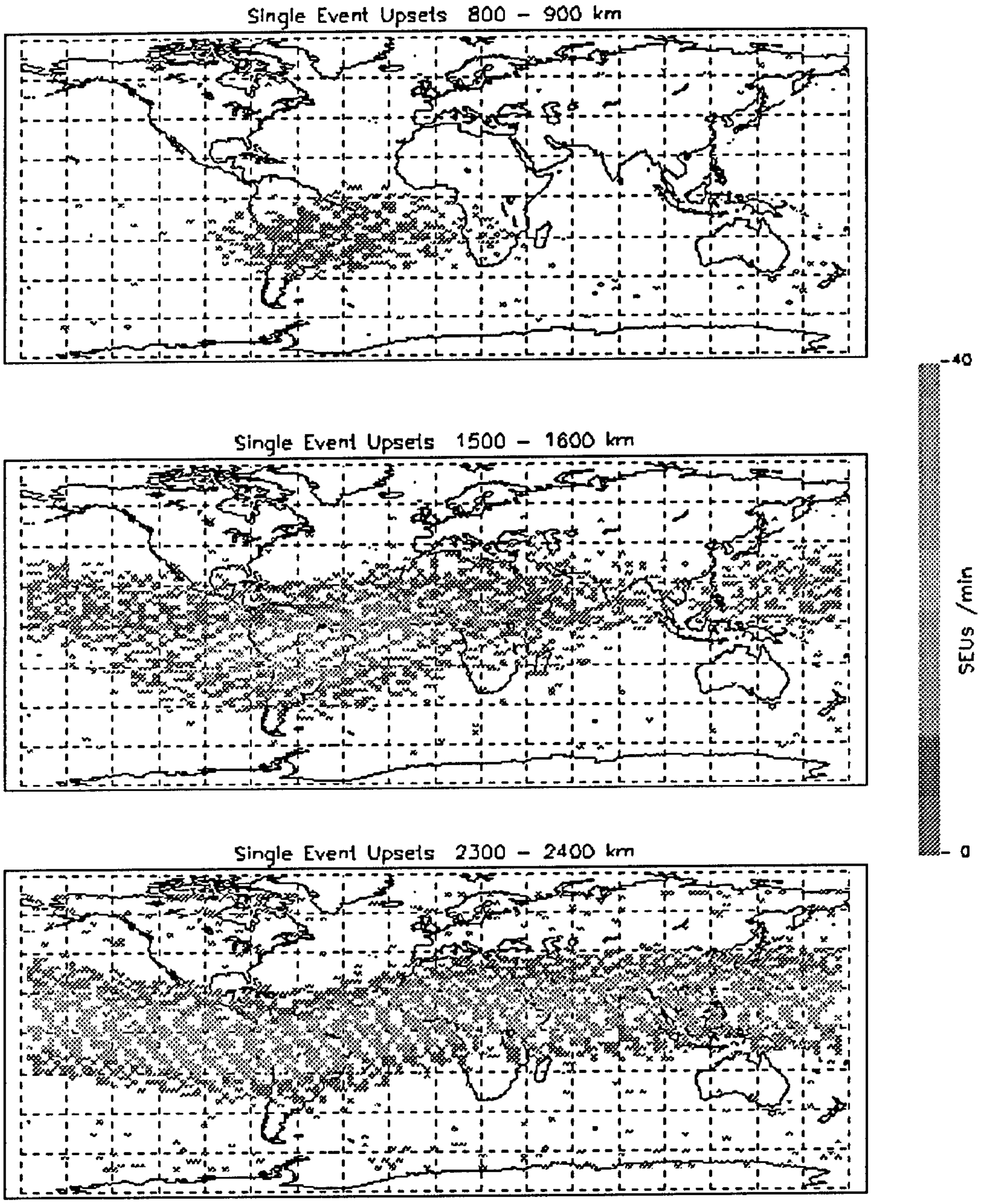

Figure 13- APEX SEU at Altitude

6.0 L-SHELL AND B/Bo BINNING

In order to provide as complete data set as possible for the CRRES spacecraft, data from a number of sensors was binned using the standardized L-Shell procedures. The Medium Energy Electron Spectrometer, Electron Proton Angle Spectrometer, Relativistic Proton Sensor, Proton Switches, Proton Telescope, Medium Ion Composition Sensor (MICS), Heavy Ion Telescope (HIT), and IMS-HI detectors were binned into 1/20th L-Shell bins on an orbit-by-

orbit basis. The 1/20th of an L-Shell binned data were subsequently binned by B/Bo by means of an indexing function.

For CRRES, the L-Shell binning effort consisted of two phases, the generation of individual files binned in 1/20th of an L-shell on an orbit-by-orbit basis and the generation of a single file of binned data for the vehicle's lifetime.

The first phase of the computerized binning process required the sensor Time History Data Base (THDB) and associated Ephemeris Files as input. For a given orbit, a file of interpolated ephemeris data (based on a cubic spline fit) containing a record for every 1/20th of an L-Shell was generated. This file was used as a look-up table in the binning process. The counts data (converted into averaged flux for selected sensors) were summed in 1/20th of an L-Shell bins. Systematic filtering techniques identified and removed 'noise points' in the raw data and thereby addressed the problem of saturated data. The averaged outputs were filtered separately for each of the detectors. Data filtering was accomplished using a sigma test. In addition to the generation of the actual data file based on the 1/20th of an L-Shell binning, informational files (a data gap file based on the sigma test and a sum of the squares file) were temporarily created to maintain a quality check on the noise filtering process. To assist in the development of analysis required for 'noise point' extraction, a PC hosted display routine for the sensor data was implemented. The routine exhibited averaged integral counts for each detector on an orbit-by-orbit basis as functions of time and selected ephemeris and magnetic field parameters. The L-Shell and B/Bo values, computed with a spline fit interpolation, were stored in the output data file along with the number of observations in each bin for future use.

The output files were sequential and comprised of a series of fixed length records. Each file contained one orbit of binned data. Each record consisted of 32-bit words comprised of time, L-Shell, and B/Bo followed by summed counts/flux data based on 1/20th of an L-Shell binning and the associated numbers of observations in each bin. These files provided the input to the second phase of the binning process.

The second phase of the computerized binning process accessed each file of 1/20th of an L-shell data created in phase I on an orbit-by-orbit basis and generated one file of binned data covering the lifetime of the satellite. These files provided input to spectrogram plotting of sensor outputs as functions of L-Shell and orbit number.

The L-Shell binned files were sequential and comprised of fixed length records. Each record of data contained one orbit of binned data. Thus, the total number of records in a file reflected the number of orbits in the period covered. Each record consisted of 32-bit words comprised of 4 header words (orbit number, year, day of year and a multiplicative factor) followed by averaged counts/flux data repeated 160 times starting at an L-Shell of 1, incrementing 1/20th of an L-Shell to a value of 8.95.

The L-Shell and B/Bo binning effort consisted of merging the sensor 1/20th of an L-shell binned files with those binned by B/Bo. The binning process was based on defining the merging period of interest, i.e., the 'active' or 'quiet' periods in terms of start and end orbits. The appropriate 1/20th of an L-shell binned files generated by phase I provided the input to the binning process. The sensor L-shell binned counts/flux data were binned by B/Bo for the period of interest by means of an indexing function coded for this purpose.

The merged output files contained 160 records based on 1/20th of L-shell bins (binned over values 1 to 9) of sensor data binned over 20 pre-defined B/Bo values (ranging from 1.000 to 7.410). The files were sequential and comprised of fixed length records. Each record contained average data for discrete 1/20th of an L-Shell bin. Each record consisted of 32-bit words comprised of record number, summed counts/flux data for 20 pre-defined B/Bo intervals followed by corresponding numbers of observations in each B/Bo bin. These files provided input to spectrogram plotting of averaged counts/flux data as a function of L-Shell and B/Bo for each energy being analyzed.

APPENDIX A - Publications and Presentations

PUBLICATIONS

M.S. Gussenhoven, E.G. Mullen, D.A. Hardy, P. Severance, D. Madden, E. Holeman, D. Delorey and F. Hanser (1995), "The Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite", IEEE Transactions on Nuclear Science, December 1995.

E.G. Mullen, K.P. Ray, R. Koga, E.G. Holeman and D.E. Delorey (1995), "SEU Results from the Advanced Photovoltaic and Electronics Experiment (APEX) Satellite", IEEE Transactions on Nuclear Science, December 1995.

M.S. Gussenhoven, E.G. Mullen, M.D. Violet, C. Hein, J.Bass, D. Madden and A. Korth (1993), "CRRES Proton Flux Maps", IEEE Transactions on Nuclear Science, 40, p. 1450-1457, Dec 1993.

A.R. Frederickson, E.G. Holeman and E.G. Mullen (1992), "Characteristics of Spontaneous Electrical Discharging of Various Insulators in Space Radiations", IEEE Transactions on Nuclear Science, 39, No. 6, p 1773-1784, December 1992.

A.R. Frederickson, E.G. Holeman and E.G. Mullen (1992), "On-Orbit Insulator Charge Storage and Partial Discharge in the Space Radiation Belts", Proceedings of the IEEE Conference on Electrical Insulation and Dielectric Phenomena, p 142-147, October 1992.

PRESENTATIONS

E.G. Mullen, M.S. Gussenhoven, D. Madden, E. Holeman and D.E. Delorey (1995), "Radiation From the APEX Satellite", 1995 Fall AGU Meeting, San Francisco, CA, December 11-15, 1995. [Invited]

K.P. Ray, E.G. Mullen et al (1995), "Solar cell degradation observed by the advanced photovoltaic experiment satellite", 1995 Fall AGU Meeting, San Francisco, CA, December 11-15, 1995.

G.P. Ginet, M.S. Gussenhoven, E.G. Mullen, D. Madden and E. Holeman (1995) "Energetic Particle Data Availability at the Phillips Laboratory Geophysics Directorate", Workshop on Radiation Belts: Models and Standards, Brussels, Belgium, 17-20 October 1995.

M.S. Gussenhoven, E.G. Mullen, D.A. Hardy, P. Severance, D. Madden, E. Holeman, D. Delorey and F. Hanser (1995), "The Low Altitude Edge of the Inner Radiation Belt: Dose Models from the APEX Satellite", 32nd Annual International Nuclear and Space Radiation Effects Conference, Madison, Wisconsin, 17-21 July 1995.

E.G. Mullen, M.S. Gussenhoven and E. Holeman (1995), "Variations and Dynamics of MeV Electrons Over a Solar Cycle as Measured by the DMSP J4 Detector", 32nd Annual

International Nuclear and Space Radiation Effects Conference, Madison, Wisconsin, 17-21 July 1995.

M.S. Gussenhoven, E.G. Mullen, D. Brautigam, D. Madden, J. Bass and C. Hein (1994), "CRRES Radiation Belt Models", Workshop on the Earth's Trapped Particle Environment, Taos, NM, 14-19 August 1994. (Invited)

E.G. Mullen and E. Holeman (1994), "MeV Electrons as Measured by the DMSP J4 Detector Part I: Particle Identification and Verification", 1994 Fall AGU Meeting, San Francisco, CA, December 5-9, 1994.

M.S. Gussenhoven, E.G. Mullen and E. Holeman (1994), MeV Electrons as Measured by the DMSP J4 Detector Part II: Variations and Dynamics Over a Solar Cycle", 1994 Fall AGU Meeting, San Francisco, CA, December 5-9, 1994.

M.S. Gussenhoven, E.G. Mullen, C. Hein, J. Bass and D. Madden (1994), "Pitch Angle Distributions of Protons in the Inner Radiation Belts", 1994 Spring AGU Meeting, Baltimore, MD, May 23-27, 1994.

A.R. Frederickson, E.G. Holeman and E.G. Mullen (1994), "Characteristics of Spontaneous Electrical Discharging of Various Insulators in Space Radiations", given to the College Military Royal and University of Montreal, Quebec, March 25, 1994. (Invited)

E.G. Mullen, M.S. Gussenhoven, M.D. Violet, C. Hein, J. Bass and D. Madden (1993), "CRRES High Energy Proton Flux Maps", 1993 Fall AGU Meeting, San Francisco, CA, Dec 6-10, 1993.